MESUR-based Mars Sample Return Study

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in 1996, the MESUR Pathfinder mission will test a new U.S. spacecraft for delivering small payloads to the Martian surface. The MESUR-based Mars Sample Return Study examines the feasibility of using a Pathfinder derivative, as well as the techniques and infrastructure expected to be developed for MESUR Network, to support a small, low-cost sample return mission launching as early as 2003. The total life cycle cost goal for this mission is $1B.

The baseline scenario starts with the launch of an Atlas IIAS launch vehicle containing a Mars Ascent Vehicle (MAV) and an Earth Return Vehicle (ERV). The MAV is packaged inside a derivative of the Pathfinder lander. Like Pathfinder, the lander enters directly from hyperbolic approach, deploys a parachute, and lands on airbags. At the same time, the ERV is propulsively inserted into Mars orbit. The lander stays on the surface for up to one month, collecting samples by means of a modified MESUR Network microrover or other device, and then ascends into a low Mars orbit. The ERV rendezvous with the MAV, aseptically transfers the sample, and sends the sample capsule on its way to a direct Earth entry and collection via air snatch.

Preliminary mission design and flight system concepts are described, along with sampling goals and technology development needs for this scenario. Flight system designs developed by the Martin Marietta Corporation in support of this study include a Mars ascent vehicle (MAV) weighing approximately 100 kg.

INTRODUCTION

MESUR: Mars Environmental Survey Mission

As part of the Mars Environmental Survey Mission (MESUR), the Discovery mission Pathfinder will be launched in 1996, in order to test critical elements of a new U.S. Mars lander design, and deliver a small science package to the Martian surface. The Pathfinder mission

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scenario involves the launch of a single lander on a Delta launch vehicle, direct entry into the Martian atmosphere, the deployment of a parachute, and finally a rough landing on airbags. The lander may tumble for a period of time before coming to rest, at which point the tetrahedron-shaped lander will unfold and start science data taking. The solar-powered lander will operate on the surface of Mars for up to 30 days, taking pictures and meteorological observations and relaying the data directly to Earth. A microrover will also be utilized to deploy an alpha proton x-ray spectrometer for chemical analyses of surface materials. As part of the Discovery suite of missions, the development cost of this mission must not exceed $150 Million.

The results of Pathfinder will be instrumental in the development of the subsequent MESUR Network mission, which involves the placement of a number of small, instrumented landers on the Martian surface. These landers, planned to be launched over successive opportunities between 1998 and 2003, would operate simultaneousl y on the surface of Mars for several Earth years, providing meteorological and seismometric data. The development cost goal for the mission is currently $1 Billion.

MllSUR-based Mars Sample Return Mission Study

The study currently in progress examines the feasibility of using the technics], managerial, and operational infrastructure expected to be developed by the MESUR project, to enable a small, low cost Mars sample return mission. The guidelines for this study arc summarized belo w:

- Maximum appropriate use is to be made of the MESUR infrastructure (entry and landing systems, surface operations devices [μrovers], descent and post-landing data from landers, etc.) to enable a small, low cost sample return mission.
- The cost goal is $1 Billion, including launch and operations costs, for a single landing.
- The first launch opportunity is 2003, with backups in 2005 and 2007.
- At least 5 separate rock samples (total mass approximately 100 gin), arc to be collected and preserved at a temperature of -10"C. The sampling device must be able to collect samples at least 100 m from the lander.
- Key technology development needs for this mission (status, development schedule, and rough order of magnitude costs) will be identified. Technology innovation is encouraged.
- Assume successful completion of MESUR Pathfinder and Network.

These guidelines arc based on discussions with the sponsor (NASA's Solar System exploration Division) and interactions with the Mars Science Working Group and other members of the Mars science community.

## MISSION CONCEPT

Pathfinder-based Concept

in order to maintain maximum commonality with the MESUR infrastructure, the feasibility of placing a Mars ascent vehicle (MAV) inside a minimally modified Pathfinder tetrahedron has been the primary focus of this study. The Pathfinder design was chosen as the point of departure for this study for two reasons. First, of all the concepts currently known to be under consideration for MESUR, Pathfinder has the greatest payload delivery capability. The current Pathfinder entry system (aeroshell and back cover), parachute, airbags, and lander shell, is capable of delivering approximately 100 kg of payload to the Martian surface. Concepts for the follow-on Network landers arc still being formulated, but arc likely to have much smaller payload delivery capabilities. 'l he second reason for choosing Pathfinder as the delivery vehicle for this mission is that it represents the most mature of all the MESUR lander designs currently in existence.

Each edge of the Pathfinder tetrahedron measures approxima tely 1 m, yielding a very small interior volume for housing the MAV. The mass of the M AV must also be constrained such that the total mass of the loaded lander is approximately the same as that of the current Pathfinder lander, so that the parachute, aeroshell, and airbag do not have to be resized. Finally, the MAV must be capable of withstanding the same rough landing undertaken by the Pathfinder lander, which includes an initial shock of 50 g's, followed by an interval of tumbling before the lander comes to rest.

in order to keep the MAV as small and lightweight as possible, it was decided to utilize a Mars orbit rendezvous mission architecture. in this concept, the MAV need only ascend to a low Mars orbit, where it is met by a separate vehicle (the Earth Return Vehicle, or ERV) which rendezvous and docks with the MAV, aseptically collects the sample from the MAV, and performs the injection burn to rctu rn the sample capsule to Earth. This technique formed the basis of the Mars Rover Sample Return Project[1] n the past, other mission architectures have also been studied, which place greater requirements on the MAV, leading to MAV masses unacceptably large for the restrictions of the current study. in the Earth orbit rendezvous concept, the MAV ascends to Mars orbit, and then performs the trans-Earth burn itself, 1 t then places itself into an elliptical Earth or-bit, where the sample is collected by means of a separate vehicle. The direct return concept has the MAV performing not only the trans-Earth injection burn, but also delivering the sample return capsule directly into Earth's atmosphere, without the intervention of a separate vehicle of any kind. Examples of these concepts applied to small Mars sample return missions can be found in references 2 and 3.

Mission Scenario

The baseline scenario, as illustrated in Figure 1, starts with the launch of an Atlas IIAS launch vehicle containing the lander and the ERV. Like Pathfinder, the lander enters directly from hyperbolic approach, initial deceleration being provided by means of a blunt-cone aero·
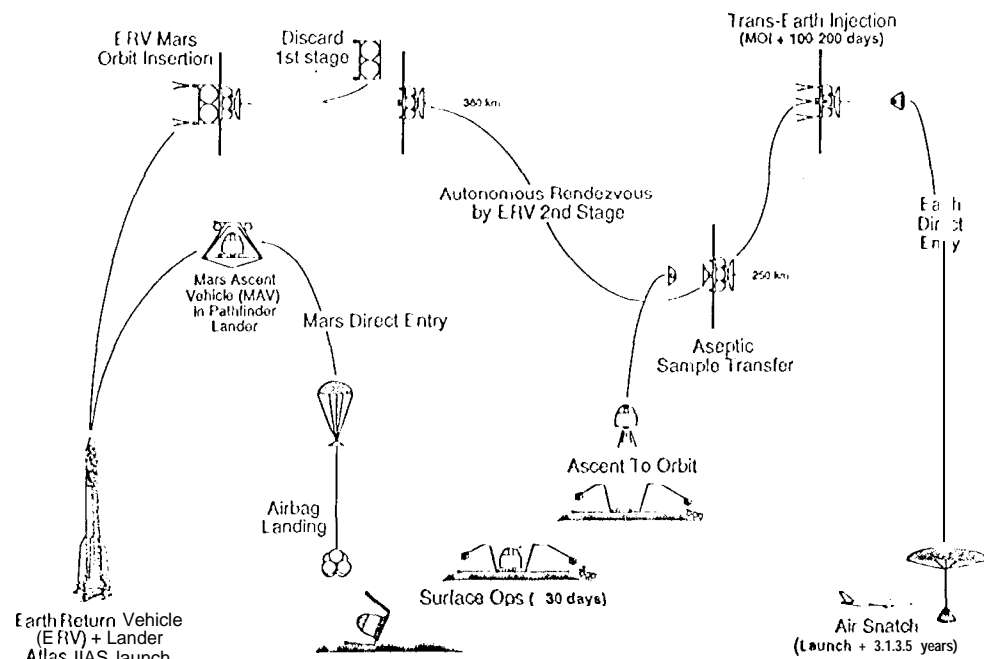
Figure 1 MESUR-based Mars Sample Return Scenario

shell. After entry, the aeroshell and back cover arc discarded, and a parachute is deployed. Again, like Pathfinder, airbags provide terminal impact attenuation, after which the tetrahedron-shaped lander may tumble for some interval until it comes to rest. Soon thereafter, the tetrahedron opens up to reveal the MAV. During this time, the ?-stage ERV is propulsively inserted into Mars orbit, at an altitude of approximately 380 km. The first stage of the ERV is discarded after orbit insertion. The lander and MAV stay on the surface for up to one month, during which time the samples are collected. The baseline design involves the use of a modified MESUR Network microrover, which is sent out to collect the samples and return them to the vicinity of the lander. A separate arm on the lander is used to transfer the samples from the rover to the sample canister. Once the samples are obtained, the MAV ascends into a low, circular Mars orbit with an altitude of approximately 250 km. Using ground-based updates, the ERV performs the rendezvous, approaching to within approximately 1 km of the MAV, at which point the on-board systems take over for proximity operations and docking. The sample is aseptically transferred from the MAV to the ERV, and placed in the return capsule. The ERV then performs the trans-Earth injection burn. 'The time elapsed between Mars orbit insertion and trans-Earth injection is 100 to 193 clays. During Earth approach, the sample return capsule separates from the ERV, and inters directly into the Earth's atmosphere, where, after initial deceleration by means of an aeroshell, a parachute is deployed to slow it further. The sample capsule is collected by airplane via an air snatch, before the capsule reaches the ground.

MISSION DESIGN

Opportunities

In identifying suitable opportunities for this mission, the requirement to keep all costs as low as possible led to a desire for short mission durations. The opportunities identified for this study all involve total mission durations (Earth launch to Earth return) of less than 3.5 years. The time from Mars arrival to trans-Earth injection, in all cases, is 100-193 clays, which should provide sufficient time for the lander to collect the samples and for the MAV to ascend to orbit for rendezvous. Keeping the time at Mars as short as possible keeps costs down, because this is the interval of greatest operational complexity and activity. Table 1 summarizes the opportunities identified for this mission, and lists mission data across a 20 day launch period. In this table, C3 is the square of the hyperbolic excess velocity at Earth launch, and V∞ refers to the magnitude of the hyperbolic excess velocity, either incoming or outgoing.

Table 1

MISSION OPPORTUNITIES

LAUNCH		MARS ARRIVAL		MARS DEPARTURE		EARTH ARRIVAL	
Launch Date	C3 (km^2/s^2)	Arrival Date	incoming V∞ (km/s)	Departure Date	Outgoing V∞ (km/s)	Arrival Date	Incoming V∞ (km/s)
5/27/2003	9.8	11/25/2003	3.1	3/4/2001	2.6	7/14/2006	3.6
6/6/2003	9.4	11/26/2003	3.?	3/5/2001	2.6	7/15/2006	3.6
6/16/2003	10.2	11/28/2003	3.2	3/7/2001	2.7	7/16/2006	3.7
10/25/2004	11.9	1/27/2007	2.8	7/21/2037	3.2	4/29/X108	3.0
11/4/2004	9.8	1/31/2007	2.8	7/21/2037	3.2	4/29/2(X)8	3.0
11/14/2004	8.9	2/2/2007	2.8	7/21/2037	3.2	4/29/2038	3.0
11/21/2006	10.3	1/19/2009	3.1	7/31/2009	2.8	5/24/2010	2.8
12/1/2006	9.3	1/25/2009	3.1	7/31/2039	2.8	5/24/2010	2,8
12/11/2006	9.0	2/15/?009	3.3	7/31/2039	2.8	5/?4/2010	?,8

ERV AV Requirements

The AV requirements for the ERV associated with these opportunities arc quite challenging, since the ERV must not only perform the Mars orbit injection and maneuvers to match mbits with the MAV, but also the trans-Earth injection. Table 2 summarizes the ERV AV requirements. The AV requirements for the Mars Ascent Vehicle arc opportunity-independent, and will be covered in the section on flight system designs.

Table 2
ERV AV Requirements

Opportunity	ERV Stage 1* (m/s)	ERV Stage 2** (m/s)
2003	?5.54	2513
2004	2367	?797
?006	2630	2590

* includes injection into .380 km circular orbit, with 3% gravity loss, plus 100 m/s for Earth-Mars cruise navigation and 20 m/s contingency.

** includes trans-Earth injection from 380 km circular orbit, with 1% gravity 10SS, plus 84 m/s transfer AV from 380 km to 230 km, 100 m/s rendezvous AV, 71 m/s transfer AV from 250 km to 380 km, 50 m/s for Mars-Earth cruise navigation, 40 m/s for Earth divert AV, and '20 m/s cent ingency.

SAMPLES AND SITES

Sample Characteristics

Based on consultation with members of the Mars Science Working group and other members of the Mars science community, minimum sampling goals for this mission have been identified. These requirements were designed to provide valuable science return, but keeping in mind the severe restrictions associated with this mission configura t ion. Table 4 summarizes these goals, and illustrates the degree to which the Pathfind er-based design meets or exceeds these objectives. in Table 3, the sample size requirement is associated with (he need to obtain unweathered material. The required sampling radius, i.e. the minimum distance the sampling device must be able to reach to collect the sample, is quite approximate, and may well change, based on the results of other missions like Pathfinder, Net work, and the upcoming Russian Mars landers. As indicated, the l'athfir~dcr-based design is capable of meeting or exceeding the minimum sampling goals outlined for this study. The science return afford ed by these samples is described in the section "Value of a Small Mars Sample Return".

Site Accessibility and Selection

The ability of this design to reach a given site is restricted to the current capabilities and limits of the Pathfinder lander, and the park orbit inclination for the ERV. At present, Pathfinder is restricted to sites with a maximum altitude of approximately 2 km. Also, because the lander is solar-powered, the range of acceptable latitudes is dictated by the solar declination at the landing site at arrival. The lander should be operable within ± 30° of the equator for the 2003 opportunist y, and + 10" to -50" for the 2004 and 2006 opportunit its. The park orbit of the ERV is at an inclination of approximately 40", which means the maximum South

latitude reachable during the '0ft and '06 opportunities is -40". The 3-σ major axes of the landing ellipse are 1 20 km along track and 35 km cross track.[4]

The landing site restrictions suggest that the lander should be targeted to the center of a large, relatively homogeneous geological unit. Also, for reasons of landing safety, it may be useful to choose a landing area whose characteristics have already been determined by means of a previous lander, such as Network or Viking.

Table 3
SAMPLE REQUIREMENTS

	Minimum Goals	Pathfinder-based Design
mass or size / sample	2 cm min. dimension rock	≥ 2 cm min. dimension rock
# samples / landing site	5 rock, plus soil & atmosphere minimum ~ 100 gm rock	≥ 5 rock, plus soil & atmosphere total sample -500 gm
instrumentation	color imaging (e.g. Viking camera)	color imaging (lander & rover) AΓX on rover
sampling radius	100 m	Network prover capability
preservation	≤ -10° C	≤ -10° C
sample acquisition	friability detection	friability detection
surface time	a few weeks	up to 30 days

FLIGHT SYSTEM DESIGNS

Mars Ascent Vehicle and Lander

The Mars Ascent Vehicle is carried to Mars inside a Pathfinder-based self-righting tetrahedron shaped lander, as illustrated in Figure 2, This assembly is packaged in a 2,65 m diameter blunt cone aeroshell designed for a direct entry from approach at an entry velocity of up to 7 km/s. The aeroshell uses the same 140° cone angle that was proven on Viking. A cruise stage supports the spin-stabilized aerocraft on the flight to Mars by providing solar arrays, antennas, attitude control, and propulsion for trajectory correction maneuvers. The single stage MAV performs the ascent ΔV of 4275 m/s with a pressurized bipropellant propulsion system that has an engine thrust of 800 N. The propellants are Chlorine Pentafluouride (CPF) and hydra zine, with an ISP of 355 seconds. The high ISP is made possible) by a pressure-fed system (inlet pressure of 700 psi), which allows the mass of the engine and the lines to be reduced significantly. The MAV has an aerodynamic fairing to reduce drag loss and to protect it from aerothermal heating during Mars ascent. The total estimated MAV mass is 107 kg, including contingency. The MAV structure is sized to survive a rugged landing with loads up to 50 g's in any direction. 'This required changes in the propulsion tank mounts, the engine support ring, and the equipment deck, compared with an "ultralight" soft-landing MAV, On the ground, the
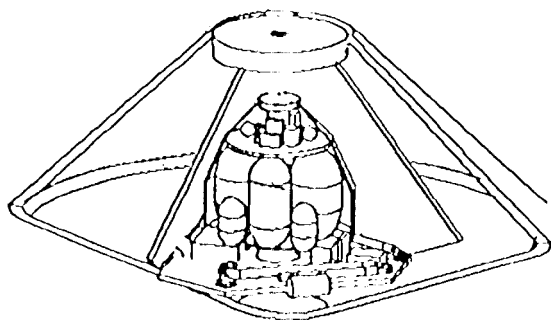
Figure 2   Mars Ascent Vehicle inside a Pathfinder Tetrahedron

MAV is supported by the lander's solar arrays; it is powered during ascent by batteries, and is powered during its wait in orbit by solar arrays.

The MAV uses an X-band telecom system to communicate to the ERV. Using bent-pipe doppler, both vehicles can be tracked with only the ERV's link to Earth. When on the surface, the MAV and lander use three horn antennas on the lander for a direct link, including control of the rover. A sample transfer arm transfers samples from the rover into the canister on top of the MAV. A second arm is also included on the lander, for redundancy. The lander also carries extra batteries to support surface operations. The total lander mass is 421 kg, including MAV.

I)ry mass has been significant] y reduced compared to previous designs by combining the electronics for power, commands, data, and telecom subsystems into one integrated system which shares its resources. The MAV and lander functions and equipment arc further shared to reduce cost and mass. For example, the MAV'S centralized computer is used for control and sequencing of events during entry, descent, and landed operations on the Mars surface as a cost and mass savings.

Earth Return Vehicle and Sample Return Capsule
    The Earth Return Vehicle (ERV), illustrated in Figure 3, carries the Sample Return Capsule (SRC) to Mars and back to Earth afire rendezvous with the MAV in Mars orbit. The

launch mass of the ERV is 801kg, including the SRC. The ERV is designed as a two stage vehicle rather than a single-stage one to save mass while achieving a total AV of over 5000 m/s. The ERV must be 3-axis stabilized to accomplish the rendezvous and docking with the MAV. The ERV first stage performs the cruise maneuvers and the Mars orbit insertion (MOI) AV. The first stage is jettisoned after correcting any MOI residuals. The ERV is capable of staying in Mars orbit for up to one year, although the maximum wait time is expected to be no more than 200 days. Power is provided by a deployed solar array and rechargable batteries. The telecom data is broadcast in the X-band frequency over a horn antenna to a 70-m DSN station. The second stage of the ERV carries most of the avionics as well as the SRC.
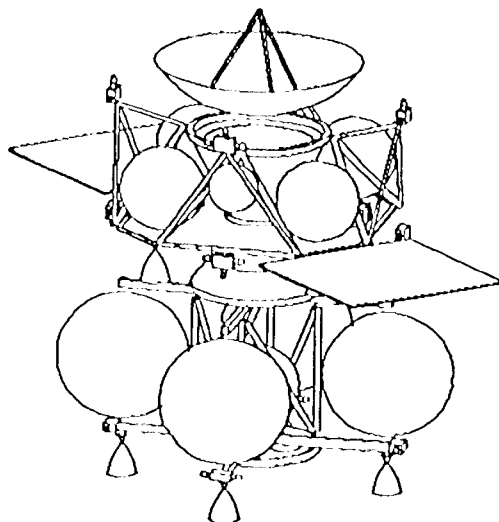

Figure 3 Earth Return Vehicle

The autonomous docking is carried out with the aid of a camera and a six-DOF attitude control system. After the docking, the sample is aseptically transferred to the SRC and sealed within it. The MAV and the docking equipment are then jettisoned and left in Mars orbit to reduce the mass of the return stage. The trans-Earth injection burn is accomplished in two burns to avoid gravity losses of a single long burn. The ERV provides support of the SRC over the long cruise back to Earth. Shortly prior to Earth encounter the SRC is spun up to 5 rpm and released from the ERV on a direct entry trajectory. The ERV could perform a divert maneuver to avoid entry if desired. The 0.6 m diameter SRC enters the atmosphere at 11,7 km/s and ballistically slows to sub-Mach velocities, at which time a parachute is deployed to slow the capsule to a 8 m/s terminal descent rate. The SRC broadcasts a beacon signal and is recovered by an air snatch

am-t carried to a receiving facility. A flotation system or crushable materials are also carried on the SRC in the event that the air snatch is unsuccessful.

Launch Margins

Cost restrictions limit the choice of launch vehicles to small and intermediate launchers, such as the Delta or Atlas. This study has examined the possibility of launching the ERV and the lander separately, using two Delta II 7925 vehicles, and also using a single Atlas IIAS to launch the ERV and lander together. The two-Delta option involves launches at least 10 days apart. As a result, the launch dates indicated in Table 1 would be used for the ERV, and an earlier or later date would be used for the launch of the lander, which, being lighter, can be accommodated by the Delta at higher C3's. C3's for the lander launch opportunities range between 17.2 and 24.3 km^2/s^2. For the dual Delta launch option, the launch margin for the lander is greater than 250 kg; the ERV launch margin is above 100 kg. Use of the Atlas IIAS allows a launch margin greater than 500 kg for the combined ERV and lander. These launch margins include appropriate launch reserves and allowances for adapter mass,

Technology Development Needs

in order to enable this mission the following technologies are required: high I sp lightweight high pressure propulsion; autonomous rendezvous and docking sensors and software; lower mass structures; aseptic transfer techniques and docking mechanisms; integrated low mass avionics; lightweight inertial grade gyros; and sample path de-contamination and protection. Other technologies which are enhancing for cost and mass reduction: non-mortar deployed parachute systems, lighter weight air bags, high energy density lightweight batteries, lightweight solar arrays, lightweight high temperature heat shields, high efficiency transmitters and lower mass thermal insulators.

Many of the technologies required for a MESUR-based sample return are in development by MESUR or Clementine missions. in particular, parachutes and airbags for terminal deceleration will be proven by MESUR Pathfinder. Advanced lc)n~-burn lightweight propulsion and more accurate light weight gyro packages are needed technologies that are not currently assured. Clementine has a lightweight gyro, but it is not accurate enough for the MAV ascent. JSC is planning to test long burn time lightweight propulsion technology (MM} I/NTO) in 1993. Low mass, high temperature materials are being developed for the NASP and may be useful for both the MAV and the basecover.

Lightweight integrated electronics are being developed on the Pluto Fast Flyby Mission and MESUR Network and should be available in time for the sample return mission. Advanced propulsion by Aerojet for the Advanced Liquid Axial Stage (ALAS) was demonstrated in 1992. A flight test has been proposed for 1994 aboard the COMET (Commercial Experiment Transporter), or perhaps on Wakeshield 2, which will demonstrate autonomous rendezvous, docking, and sample transfer in Earth orbit.[5] Autonomous rendezvous sensors and software will also be tested on the the Clementine Asteroid Intercept mission in 1994, and on the

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SPAS/Shuttle mission in 1996. Integrated docking will also be demonstrated on SPAS. Sample handling devices for rock sizing and chipping will be developed in 1994 under funding by PIDDP (Planetary Instrument Definition and Development Program).

PLANETARY PROTECTION

Some level of protection of the planet Mars from biological contamination by terrestrial organisms is a requirement on every landed mission. The current plans for MESUR Pathfinder and Network involve a level of biological cleanliness consistent with Viking pre-heat sterilization levels. The most recent protocols developed for planetary protection indicate that this is sufficient for Mars landers whose primary goal is not life detection[6] However, for sample return missions the procedures for reducing the level of bioburden on the spacecraft may be more stringent to prevent organisms transported from Earth from contaminating the Mars samples. If such contamination were to happen, the screening techniques u sed back on Earth would give a false positive for life on Mars, which could not only be misleading, but could also invoke handling protocols and additional screening experiments that might consume much of the small sample. A single bacterial spore could be sufficient to contaminate the sample. Various species of spores are known which can withstand ultrahigh vacuum and cryogenic temperatures, and are quite resistant to radiation as well. in the course of this study, a number of possible remedies to this problem have been considered. Additional study must be undertaken to select the technique which satisfies the evolving planetary protection protocols.

One possible approach may be to accept the potential contamination of the sample by Earth organisms, and the consumption of (possibly important) portion of the sample in biohazard analyses. As the following section indicates, the primary science goals of this mission are related to inorganic geochemistry, as opposed to life detection, As a result, the possibility of a false Mars life-positive reading might be an acceptable trade for the relatively low cost associated with MESUR-level sterilization. Because there may be some doubt as to the terrestrial or extraterrestrial provenance of any detected organisms, it maybe necessary to sterilize those portions of the sample intended to be distributed outside the confines of a sealed environment. Any geochemical analyses which would be adversely affected by the sterilization procedure would be done in the sealed environment, prior to sterilization.

Another approach would be to subject a portion of the lander to a higher level of sterilization. In this case, then not only the sample canister but also the sampling tools, the exterior surfaces of the lander, and the rover would need to have very low residual bioloads. Using many of the cleaning techniques and component sterilization procedures developed for the Viking lander missions, bioburdens can be reduced such that the probabili ty of round-trip contamination would be <10E-6. Detailed engineering design evaluation is necessary to determine the most cost effective combination of methods for achieving this level.

The most expensive option would involve Viking-level sterilization of the entire lander/MAV assembly. It is unlikely that this level of sterilization could be achieved within the cost confines of this study, due to the need for more stringent component qualification.

in addition to avoiding forward and roundtrip contamination, it is also necessary to treat Martian samples as possibly containing material which could be a biohazard to Earth organisms. Although this "back contamination" possibility is considered extremely remote, the risk could be publicly perceived as highly consequential]. For these reasons, we have designed into our MSR mission concept the ability to aseptically transfer the sample canister from the ascent vehicle so that Martian material and all surfaces of the sample return canister, including its exterior, are kept physically isolated from the Earth return vehicle by a biobarrier film which is sealed around the canister. The method of this aseptic transfer is illustrated in Figure 4.
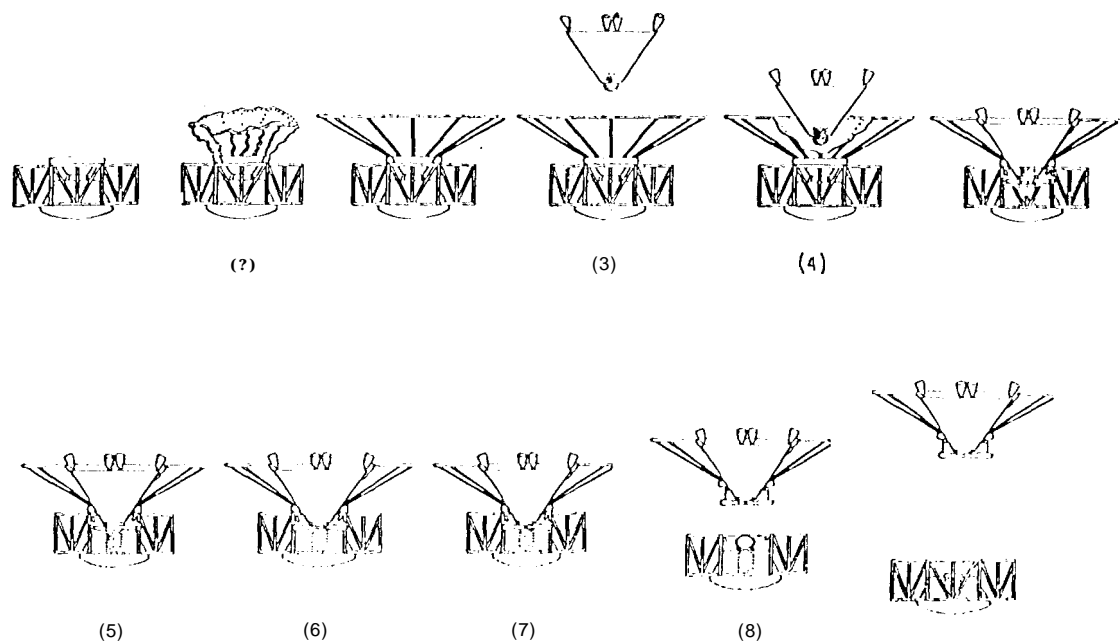

Figure 4 Aseptic Transfer

VALUE OF A SMALL MARS SAMPLE RETURN

The scientific objective of this mission is to obtain documented samples of small rocks, soils, and the atmosphere so that a wide range of sophisticated, highly sensitive analysis techniques can be applied in the best laboratories here on Earth. Sophisticated method S such as isotope geochronology (age dating), x-ray and electron diffraction (mineralogy), neutron activation analysis (ultratrace elements), ^{18}O isotope systematics, and petrologic and

transmission electron microanalysis arc just a few that arc unlikely to be implemented as flight experiments due to their difficulty but are extremely powerful for understanding sample origin and history.

The highest priority of a sampling mission is to obtain igneous rocks which contain original minerals that have not been altered. From these, the crystallization age can be determined, which in turn will allow for the first time a calibration of the geologic time scale for Mars. This is currently a relative scale based on using the cratering density (craters per unit area) of a geologic unit to estimate its age relative to other units. Theoretical calculations of the impact flux have been used to estimate absolute ages of geologic events (such as the emplacement of large lava flows), but the uncertainty is nearly half a billion years. The determination of the crystallization age of an igneous rock (millions of years since the lava crystal lized) from an identified geologic unit would allow such an unambiguous correlation bet ween the crater age scale and absolute time. Such correlations have been made on the moon, via sample return from known areas, and have proved fundamental to our understanding of its evolution. Note that although it is widely accepted that the SNC meteorites originated on Mars, and their crystallization ages have been determined, it is not possible to determine the crater/age correlat ion from these objects because it is not known from which locat ion on the planet the SNCS came. Other science objectives arc to evaluate the uniformity of rock types at a given site and to compare flow morphologies with geochemical and rheological propert ies of the source lava.

From weathering rinds on the surfaces of individual rocks, the more recent weathering environment can be inferred. The role of reactive water films or photochemical species at cold temperat ures, may become better understood. Alteration products such as clays, salts, and iron oxyhydroxides will provide clues to these processes. Evidence for erosion and differential abrasion documents the history of local wind activity. Because none of the SNC meteorites represent surface rocks, they do not necessarily reflect this environment.

The chemical, mineralogical, and physics] nature' of the expected extensive suite of minerals and amorphous products in the Martian soil should provide information relevant to long-term climate. Because many minerals can only form under restricted conditions, the environment and its influences even in ancient times may be accessible to investigation. Although there arc traces of alteration minerals within some SNCs, they do not correspond one-to-one with the implied mineralogy of the bulk surface soils.

On the Viking mission, it was discovered that one or more oxidizing compounds exist in the soil and possibly also the atmosphere. As a result, most or all organic compounds arc eventually destroyed and microbes may not be able to exist. The Mars oxidant experiment (MOx) on the Mars '94 mission will perform the first attempt to detect these oxidants by new techniques. With a returned sample, it will be possible to apply an entire battery of tests by which to understand the phenomena of the highly oxidizing environment on Mars.

in addition to oxidants, it is strongly suspected that the Martian soil contains carbonates, nitrates, and hydroxides which represent fixation of CO_2, N_2, and H_2O. This would help explain the thin atmosphere, which presumably was much thicker in the past. Sulfate, chloride, and bromide salts appear to be abundant in Martian soils, and enriched in crust deposits, but the species and forms of salts arc totally unknown at this time. Because of their high solubility, they should be important tracers of past water activity.

An extremely thorough search for biogenic and refractory organic compounds (Viking found none) and for metabolizing activity by life forms will be made on the returned samples. Assuming that extant life is not detected, it will still be of great interest to search for any evidence of extinct life, i.e., structural fossils or chemical indications of microbes in the past.

At mospheric composition, including noble gas isotopes and ul t rat race compounds, can be more exhaustively examined. It will be possible to test for transient, highly reactive photochemical species which by exposing an array of thin coatings of a variety of elements and compounds. This builds on the MOx experiment, but with the major advantage that the coatings can be returned to Earth for extensive microanalysis.

The history of Mars appears to be that of a warm, moist planet which was probably quite conducive to life early-cm, but evolved to a cold, dry planet that is now quite hostile to most life forms. The lesson of Mars is that global environments can change, more or less permanently, but how and when that happened on Mars is a mystery for which sample return provides one of our best opportunities for learning the answers. Public perception and media attention for this mission should be first-rate, with attention peaking at several different times - the launch, land ing, rover sampling, ascent and rendezvous, departure to return to Earth, the splashdown, and finally the announcements of first results. As important new discoveries arc made, the opportunity for additional interest and vicarious participation by the public will be possible, Not only the lay public, but also various scientific communities will have new-found interests in the space program. Scientists and students in such diverse fields as geology and atmospherics, as well as authorities in isotope geochemistry, cosmic ray physics, astroclimatology, meteoritics, photochemistry and many other specialties will become involved. The reservoir of sample material will become an interna t ional resource for both pedagogical and serious investigations, to be used for many decades after the return. Few other missions could achieve this degree of public interest and diversity in scientific involvement over such a long time period.

CONCLUSIONS

Preliminary designs and technology needs have been ident i fied for a small Mars sample return mission based on maximum commonality with the infrastructure expected to be developed for the MESUR Project. In particular, a very small Mars Ascent Vehicle has been designed

landing on airbags. Preliminary cost estimates indicate that, given sufficient technology development in key areas, this mission can fit comfortably within the mandated $1 B total cost.

These results are unique in a number of areas. First, this study indicates that a robust, hard-lander, specifically the Pathfinder lander, is suitable for use with a Mars sample return mission. Previous Mars sample return studies have concentrated on propulsive soft landers. More important, however, is the indication that a scientifically valuable small Mars sample return mission can be accomplished for a cost commensurate with current funding realities.

ACKNOWLEDGEMENTS

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